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# Challenges of Wireless Sensor Networks (WSN) Deployment in the Nigerian Hydrocarbon Industry

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**ABSTRACT:** The hydrocarbon industry has remained one of the most viable sector of the Nigerian economy and has continued to play a vital role in the economic growth of Nigeria. However, lately the revenue accruing from the sector has been dwindling owing to sabotage. This has necessitated the deployment of wireless sensor networks (WSN) to monitor the pipelines. This study, conducted within the framework of a qualitative research design, therefore, aimed to explore the challenges associated with the deployment of Wireless Sensor Networks (WSN) in the Nigerian hydrocarbon industry. Expert sampling was employed to gather insights from 52 managers and engineers within six hydrocarbon companies in Nigeria. The study comprised three distinct objectives, each offering unique perspectives on the challenges faced. Findings from the analysis revealed that financial constraints pose a substantial obstacle to WSN deployment, with 59.23% of respondents acknowledging their impact. In contrast, regulatory and compliance challenges were deemed less impactful, with 61.54% of respondents viewing them as non-obstructive. Resistance to change and a lack of awareness among industry stakeholders were considered significant obstacles, with a cumulative 55.77% acknowledging their impact. Concerns about encryption and secure communication protocols were paramount, with 84.62% expressing a strong sentiment. Similarly, inadequate cybersecurity measures and susceptibility to cyberattacks were notable concerns, with 78.85% of respondents strongly agreeing. In conclusion, this study underscores the multifaceted challenges associated with WSN deployment in the Nigerian hydrocarbon industry. Financial constraints, technical difficulties, cybersecurity, regulatory compliance, resistance to change, technical expertise, infrastructure compatibility, energy efficiency, and device coverage all contribute to the complexities faced by industry stakeholders. Addressing these challenges is crucial to harnessing the potential benefits of WSN technology for enhanced monitoring and security within the hydrocarbon sector.

## I. INTRODUCTION

In countries that have deposits of oil and gas resources and do make use of transmission pipelines for oil and gas distribution, it is desired that the security and overall integrity of such pipelines should have the minimum possible degradation or outright disruption. This is because for such oil producing countries, these transmission networks form an important part of the national energy-transportation infrastructure, which in turn is vital to the stability and growth of the national economy [1]. The situation becomes even more critical for countries that have large deposits of this so-called black gold, and whose economy is largely oil-based, an example of which is Nigeria. Since these transmission pipelines are operated at high pressure, pipeline failure would inadvertently cause severe damage to human health and property, interruption of gas or oil supplies, and consequently economic downturn.

Centralized monitoring of oil and gas installations in general and pipelines in particular lack in the aspect of intelligent sustainable monitoring since long. This difficulty not only comes from the length of the pipeline infrastructure but also from the tough terrain and intense environment characteristics [2] Though, various techniques have been proposed for pipeline monitoring, mostly based around wireless solutions; an integrated solution for optimized reliable sensing to secure and timely data transfer over a remote control room is still lacking. Wireless Sensor Network (WSN) technology has gained much importance for structural health monitoring applications over the years due to rapid advancements in underlying technologies like sensing capability and resolution, communication protocols, processor speed, energy harvesting and embedded systems. These developments are gradually being adopted in oil and gas industry to automate processes and to empower the system with more control [3], [4]. The use of sensors and actuation methods have also gained strategic importance due to factors like business intelligence, competitive edge, time to market, quality and reliability standardization for industry related fluid and commodity movement, particularly the transfer of energy related products like oil and gas. Oil and gas industry has benefited from technological advancements, ranging from tiny sensors to actuators and from small scale instrumentation to full scale industrial automation. Quite recently, WSNs

have started to play their role in different sections of oil and gas related industry [5]. WSN technology is mostly oriented around power constrained solutions since sensor nodes are deployed with view point of long life operation and reliability.

However, in harsh and tough terrains as in pipeline structures, sensor nodes may suffer death under a wide range of catastrophic events from earthquake to explosions and network related attacks or even power depletion [6]. Hence, a rugged design and practicality of sensor node according to the environment to be monitored and application at hand is a critical task. The power issue has been addressed to some extent by employing 'harvesting energy' techniques, yet these are still in development phase [7]. Since oil and gas sector heavily relies on pipelines for distribution purposes and processing facilities, these need to be monitored in real time for any leakages, damages or potential hazards. Without these measures, a leakage can both be financially devastating and can pose even bigger environmental hazard. Automation of pipeline monitoring and reliable measuring of any infrastructural faults can thus provide immense benefits.

The Nigerian hydrocarbon has in recent times continued to witness numerous attacks and vandalisms on its facilities owing to poor security orchestrated by inadequate monitoring measures. Thus, many stakeholders have proposed large deployments of wireless sensor networks (WSN) as a panacea to the present inefficient system. To this end, it is worthwhile to study WSN in details with a view to understand its suitability in the Nigeria terrain since mainly challenges are related to real world environment. It is pertinent to note that wireless sensor networks, as promising as they are, still have some challenges militating against its deployment in the hydrocarbon industry globally. The challenges are worsened considering the peculiar situations of the Niger Delta region of Nigeria where most of the critical assets of the Nigerian hydrocarbon industry are domiciled. Owing to the profound potentials of WSN in the hydrocarbon industry, it behooves on researchers to continue to explore means to overcome these challenges. To achieve this requires first and foremost an in-in-depth understanding of the challenges. Hence, this study seeks to x-ray the challenges with a view to devise countermeasures since WSN has remained the most promising panacea to the inefficient security systems in the Nigerian hydrocarbon industry.

## II. REVIEW OF RELATED LITERATURE

Husnain et al. [3] conducted a study titled "Reliable Monitoring of Oil and Gas Pipelines using Wireless Sensor Network (WSN) – REMONG," where they focused on developing a monitoring solution for oil and gas pipelines using wireless sensor networks (WSN) with a specific emphasis on reliability, particularly in detecting leaks and facilitating wireless data communication. The research employed an experimental research design, utilizing computer simulation as the primary methodology. The authors acknowledged that the progress in wireless communication and data processing technologies can be effectively harnessed in the context of wireless sensor networks. However, they also identified various challenges that need to be addressed to enhance the impact of WSN in the oil and gas industries. Notably, one of the significant challenges highlighted in their study pertains to the diverse and often harsh environmental conditions encountered in the field, which have hindered the standardization of WSN devices.

Petru et al. [6] conducted a study titled "A WSN based monitoring system for oil and gas transportation through pipelines," in which they presented the outcomes of their research related to the monitoring of extensive pipelines utilized for the transportation of oil and gas. The study employed a mobile unit for signal acquisition, processing, identification, and diagnosis, referred to as MUSAPID, which was built upon wireless sensor networks (WSN) technology. The architecture of MUSAPID was tailored to align with the monitoring system's configuration and consisted of four hierarchical levels: the central dispatcher, the zonal dispatcher, the local dispatcher, and the sensor nodes. These sensors were responsible for collecting data on the flow and temperature of oil from the monitored pipeline. The distribution of sensors along the pipeline followed an in-line pattern. However, the study proposed a cross-link schema between sensor nodes to enhance operational safety and reduce the occurrence of false alarms. Two distinct monitoring approaches were implemented, both based on comparing sensor values between pairs of successive nodes to detect rifts and leaks within the pipeline network. One of these approaches was unconventional and incorporated inter-correlation between data from two successive sensor nodes, as well as auto-correlation of temperature data. Additionally, a simple logic was introduced to minimize false alarm transmissions.

Sivi et al. [8] conducted a study titled "Mobile application and wireless sensor network for pipeline monitoring and control" in India, aiming to design a novel system for monitoring and controlling pipelines. This system incorporates a mobile application and a wireless network comprising monitoring devices and isolation valves. The mobile application functions by receiving periodic alerts whenever a leak is detected and allows for remote closure of valves associated with the affected location. The system's components include a programmable microcontroller, solenoid valve, GSM

modules, Zigbee PRO modules, and a resistor-based detection system. The coding for this system was carried out using AVR Studio, while the mobile application was developed in Android Studio using JAVA. This innovative approach enables real-time leak detection and rapid response through remote valve control, enhancing pipeline monitoring and control capabilities.

Ezeja and Ahaneku [9] in their study titled “Review on the Use of Wireless Sensor Network Systems for Oil Pipeline Surveillance,” observed that the adoption of integrated Wireless Sensor Networks (WSNs) for monitoring oil pipelines has become a prevalent practice among stakeholders in the oil and gas industry. The authors highlighted a significant challenge in oil pipeline distribution systems in Nigeria and other regions, which pertains to accurately localizing bursts and leakages. These issues are often attributed to deliberate acts of pipeline vandalism by oil thieves and criminals, corrosion, compromises in pipeline integrity during physical activities like excavations, and the natural aging and deterioration of pipelines. Ezeja and Ahaneku examined various research efforts aimed at leveraging WSN technology to address these challenges. Some of the solutions reviewed included MISE-PIPE, PIPENET, Raspberry Pi, and Arduino-based WSN systems, Acoustic Sensor-based WSNs, and SCADA (Supervisory Control and Data Acquisition) systems. Their study concluded that WSN systems have proven to be highly valuable and effective in managing pipeline bursts and leakages and have even been standardized in the IEEE 802.15.4 specification, demonstrating their potential to enhance pipeline surveillance and maintenance.

Khalid et al. [10] in their study titled “Underwater Wireless Sensor Networks: A Review of Recent Issues and Challenges,” conducted a comprehensive examination of Underwater Wireless Sensor Networks (UWSN). The study encompassed various aspects of UWSN, including underwater communication channels, environmental factors, localization techniques, media access control, routing protocols, and the impact of packet size on communication performance. The authors employed a research methodology based on an extensive review of the existing literature and the development of a mechanistic conceptual model. Throughout the study, Khalid and colleagues compared and contrasted the methodologies and approaches currently available in the field of UWSN. They discussed the advantages and disadvantages of these methodologies, with the aim of shedding light on new avenues for research and potential areas for improvement in underwater sensor networks. The ultimate conclusion of the study was that there is room for enhancing communication techniques in UWSN by taking into account the environmental factors that influence communication within underwater environments. This suggests the importance of considering and mitigating these environmental effects to develop more effective communication solutions for underwater wireless sensor networks.

### III. METHODOLOGY

#### 3.1 Research Design

As explained by [11], research design is simply the framework or plan for a study that is used as a guide in collecting and analyzing the data. Accordingly, research design is needed because it facilitates the smooth scaling of the various research operations, thereby making research as efficient as possible yielding maximal information with minimal expenditure of effort, time and money. In order to attain the objectives of this study, the researchers have employed a mixed research design which is a combination of both quantitative and qualitative research approach [12]. This research design helps to intensively explore the data collected through field survey and in-depth interviews. In terms of time frame, the researcher has employed a cross-sectional research design. Therefore, the researcher has collected the data in a particular time.

#### 3.2 Area of study

The study is carried out in Niger Delta area of Nigeria. The Niger Delta is the delta of the Niger River sitting directly on the Gulf of Guinea on the Atlantic Ocean in Nigeria. It is typically considered to be located within nine coastal southern Nigerian states, which include: all six states from the South South geopolitical zone, one state (Ondo) from South West geopolitical zone and two states (Abia and Imo) from South East geopolitical zone. The Niger Delta, as now defined officially by the Nigerian government, extends over about 70,000 km<sup>2</sup> (27,000 sq mi) and makes up 7.5% of Nigeria's land mass. More than 90% of oil and gas revenues, 80% of Nigeria's GDP, and 95% of the national budget are generated in the region [13].

#### 3.3 Determination of Sample size

The sample size of this stud consists of 52 managers and engineers opportunistically selected from the following hydrocarbon companies in Nigeria: Shell Petroleum and Development Company (SDPC), Nigeria National Petroleum



Cooperation Limited NNPC Ltd, Chevron Texaco, Exxon Mobil, Nigerian Agip Oil Company (NAOC), and Aiteo E&P Company limited. Expert sampling was used in distributing the questionnaire and conducting the interviews.

**IV. RESULTS AND DISCUSSIONS**

The analysis presented in Table 4.1 provides a comprehensive overview of the perceptions held by respondents concerning the challenges influencing the deployment of Wireless Sensor Networks (WSN) in the Nigerian hydrocarbon industry. A detailed analysis of the data reveals noteworthy insights. Firstly, financial constraints surface as a substantial impediment, with a combined total of 59.23% acknowledging its impact, while only 40.77% viewed it as a lesser hindrance. This underscores the pivotal role of financial considerations in the successful deployment of WSN within the industry. Secondly, technical difficulties and compatibility issues are a significant concern, with a combination of 42.31% highlighting a “High Extent” and “Very High Extent” of hindrance. Collectively, these findings emphasize that technical challenges constitute considerable obstacles. Thirdly, regulatory and compliance challenges, as perceived by 61.54% of respondents, are evidently viewed as not imposing obstacles to the widespread adoption of WSN technology. Finally, resistance to change and a lack of awareness among industry stakeholders were considered to have a “High Extent” of impact by 42.31% of respondents, with an additional 13.46%% indicating a “Very High Extent” of hindrance. This underscores the significance of these challenges in affecting the successful deployment of WSN within the Nigerian hydrocarbon industry.

**Table 4.1: The extent to which different challenges affect deployment of WSN in Nigeria hydrocarbon industry.**

S/N	Item	Very Low Extent	Low Extent	Some Extent	High Extent	Very High Extent	Total
1	WSN deployment in the Nigerian hydrocarbon industry is hindered by financial constraints.	13 (25%)	8 (15%)	0 (0%)	21 (40%)	10 (19.23%)	52
2	Technical difficulties and compatibility issues impede the effective use of WSN in the industry.	21 (40.38%)	9 (17.31%)	0 (0%)	17 (32.69%)	5 (9.62%)	52
3	Regulatory and compliance challenges pose obstacles to the widespread adoption of WSN technology.	32 (61.54%)	18 (34.62%)	0 (0%)	2 (3.85%)	0 (0%)	52
4	Resistance to change and lack of awareness among industry stakeholders affect the successful deployment of WSN.	8 (15.38%)	15 (28.85%)	0 (0%)	22 (42.31%)	7 (13.46%)	52

In summary, financial constraints, technical difficulties, regulatory challenges, and resistance to change are perceived as significant hindrances to WSN deployment in the Nigerian hydrocarbon industry, with varying degrees of impact according to respondents’ perceptions. These findings provide valuable insights into the challenges that need to be addressed to promote the effective use of WSN in the industry.

The presented Table 4.2 summarizes the discernments of respondents concerning the security challenges associated with the implementation of Wireless Sensor Networks (WSN) in the Nigerian hydrocarbon industry. A comprehensive analysis of the data illuminates crucial insights. Firstly, it is evident that concerns related to encryption and secure communication protocols weigh heavily on respondents’ minds, with an overwhelming 84.62% expressing a “Strongly Agree” sentiment. This consensus underscores the universal apprehension regarding the security of data transmission within WSN solutions. Secondly, the issue of inadequate cybersecurity measures and susceptibility to cyberattacks emerges as a prominent concern, as 78.85% of respondents “Strongly Agree” with this statement. This resounding agreement reflects a substantial level of anxiety regarding the cybersecurity aspects inherent to WSN technology. Thirdly, the matter of data privacy and the potential for sensitive information leakage elicit a unanimous response, with 100% of respondents “Strongly Agreeing” that these concerns hinder the adoption of WSN in the hydrocarbon sector. This unanimous agreement accentuates the paramount significance of data privacy within the industry. Lastly, the



importance of access control and authentication mechanisms is underscored by the data, with 59.62% “Strongly Agreeing” and an additional 32.69% “Agreeing” that limited access control and authentication mechanisms pose security challenges. Collectively, these responses emphasize the critical role of access control and authentication in fortifying the security of WSN deployments within the Nigerian hydrocarbon industry.

**Table 4.2: Security challenges frustrating deployment of WSN in Nigerian hydrocarbon industry.**

S/N	Item	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)	Mean	SD
1	The lack of encryption and secure communication protocols in WSN solutions hinders their deployment in the Nigerian hydrocarbon industry.	44 (84.62%)	8 (15.38%)	0 (0%)	0 (0%)	0 (0%)	52
2	Inadequate cybersecurity measures and vulnerability to cyberattacks discourage the widespread use of WSN technology in the industry.	41 (78.85%)	11 (21.15%)	0 (0%)	0 (0%)	0 (0%)	52
3	Concerns about data privacy and the potential for sensitive information leakage impede the adoption of WSN in the hydrocarbon sector.	52 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	52
4	Limited access control and authentication mechanisms in WSN systems contribute to security challenges, affecting their deployment.	31 (59.62%)	17 (32.69%)	0 (0%)	4 (7.69%)	0 (0%)	52

In summary, the data indicates that security challenges related to encryption, secure communication, cybersecurity measures, data privacy, and access control are perceived as substantial obstacles to the successful deployment of WSN in the Nigerian hydrocarbon industry. Respondents express strong concerns about these issues, emphasizing the need for robust security measures in WSN solutions to address these challenges effectively.

The Table 4.3 presented below table elucidates the perceptions of respondents regarding the technical challenges impeding the deployment of Wireless Sensor Networks (WSN) in the Nigerian hydrocarbon industry. Firstly, it is evident that a significant proportion, precisely 75%, “Strongly Agrees” that insufficient technical expertise and a skilled workforce pose formidable challenges. This consensus underscores the industry’s recognized shortage of technical acumen required for the successful implementation and maintenance of WSN systems. Secondly, compatibility issues with existing infrastructure and legacy systems emerge as a substantial concern, with 40.38% “Strongly Agreeing” and an additional 13.46% “Agreeing” that such issues hinder seamless integration. This underscores the complexity of integrating WSN with established infrastructure, reflecting the need for meticulous compatibility strategies. Thirdly, the data highlights power supply constraints and energy efficiency as critical issues, as an overwhelming majority of 82.69% “Strongly Agree” that these factors affect the continuous operation of WSN devices. This underscores the imperative of addressing energy-related challenges to ensure the reliability of WSN deployment. Lastly, the limited coverage and range of WSN devices are emphasized by 63.46% “Strongly Agreeing” along with 23.08% who “Agree” with this statement. These responses underscore the necessity for enhanced coverage and range to facilitate comprehensive monitoring and data collection within the hydrocarbon industry.

**Table 4.3: Technical challenges impeding deployment of WSN in Nigerian hydrocarbon industry.**

S/N	QUESTION	STRONGLY AGREE	AGREE	NEUTRAL	DISAGREE	STRONGLY DISAGREE	TOTAL
1	Insufficient technical expertise and skilled workforce for implementing and maintaining WSN systems.	39 (75%)	13 (25%)	0 (0%)	0 (0%)	0 (0%)	52
2	Compatibility issues with existing infrastructure and legacy systems hinder the seamless integration of WSN.	21 (40.38%)	7 (13.46%)	0 (0%)	18 (34.62%)	6 (11.54%)	52
3	Power supply constraints and energy efficiency challenges affect the continuous operation of WSN devices.	43 (82.69%)	9 (17.31%)	0 (0%)	0 (0%)	0 (0%)	52
4	Limited coverage and range of WSN devices create gaps in monitoring and data collection within the hydrocarbon industry.	33 (63.46%)	12 (23.08%)	0 (0%)	7 (13.46%)	0 (0%)	52

Collectively, these findings reveal the multifaceted technical challenges confronting WSN deployment, encompassing workforce expertise, compatibility intricacies, energy considerations, and coverage limitations. Addressing these challenges is imperative for the effective utilization of WSN technology within the Nigerian hydrocarbon industry.

### V. CONCLUSION

In this study, the security and technical challenges facing the deployment and utilization of wireless sensor Networks (WSNs) in the Nigerian hydrocarbon industry have been identified. For WSN to perform optimally and reliably in mission-critical oil and gas infrastructure and facility monitoring, the security challenges facing them must be tackled and resolved successfully. The three-tier security triad: operational, data/information and physical security of the wireless sensor network have been identified as the key security issues affecting WSN deployed in Nigerian

hydrocarbon industry. This three-triad security must be provided for reliable and efficient operation of the WSN in field monitoring; the data emanating from the WSN nodes to the base stations and control room must be made to be confidential and reliable. The communication links of the WSN must be secured against eavesdropping and denial-Of-Service attacks to protect the WSN from being hijacked and its services disrupted by criminal minded elements; most importantly, pre-emptive and proactive physical security measures should be provided at the oil and gas fields to deter or apprehend criminals who may want to vandalize oil facilities in order to steal crude oil. Efforts, also, must be made to protect the sensors installed in unattended and hostile environments such as obtainable in the Niger Delta region from being physically captured and attacked.

In the same vein, there is need for the hydrocarbon industry to invest more in research to overcome the identified technical challenges. Technical challenges such as inoperability of different WSN standards, issues relating to preservation of battery energy of the wireless sensors, Network performance etc. must be considered in order to ensure the smooth functioning and energy preservation of the wireless sensors. It is after these countermeasure solutions are provided that WSN can provide an efficient and reliable oil and gas field monitoring for an oil region full of security challenges as the Nigerian Niger Delta.

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